400-442

FABRICATION AND CHARACTERIZATION CAPABILITIES OF THE MICRODEVICES LABORATORY

Center for Space Microelectronics Technology

Jet Propulsion Laboratory

NAS 1.12/7:

READEX FICHE best copy available

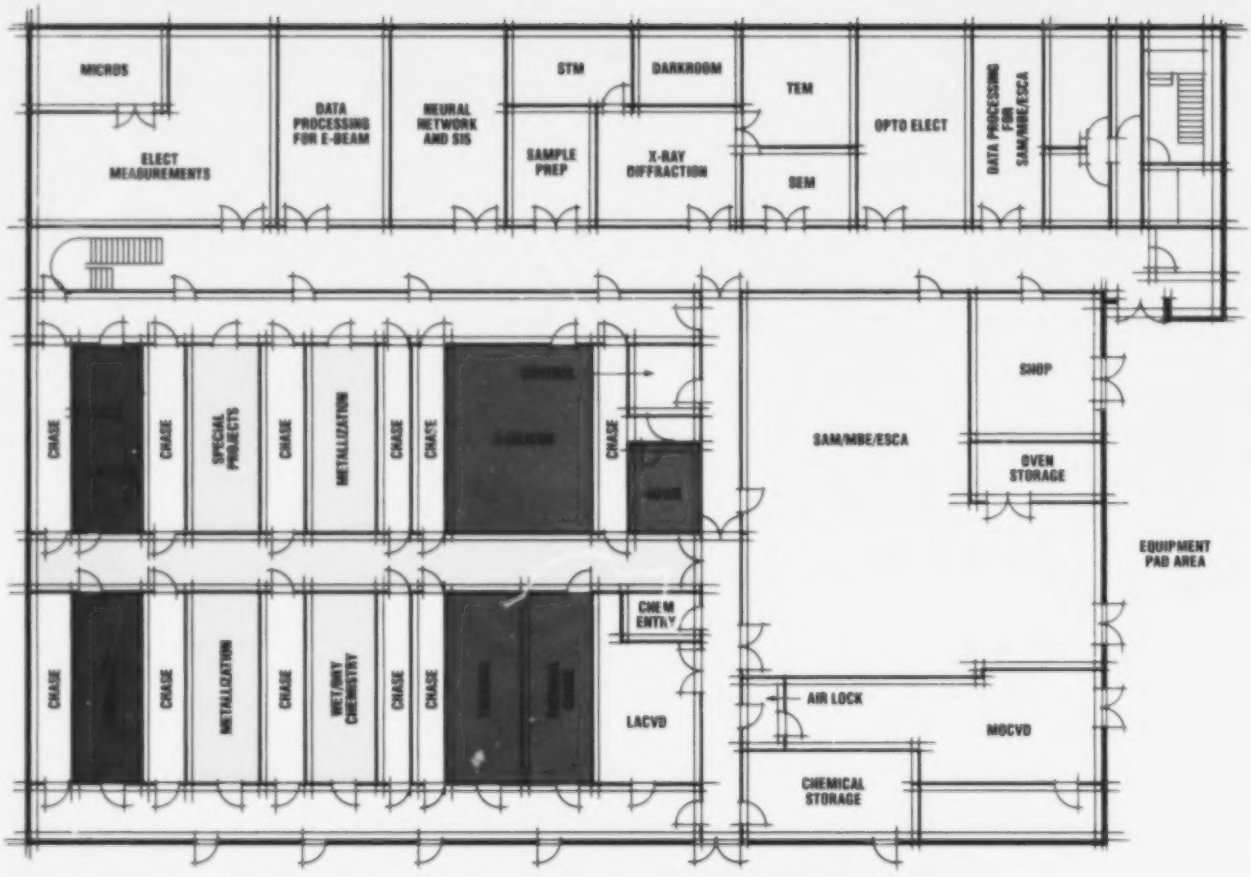
The Microdevices Laboratory (MDL) is a state-of-the-art facility dedicated to long-range research and advanced development of electronic materials and solid-state devices that support the space mission requirements of the National Aeronautics and Space Administration (NASA) and the U.S. Department of Defense (DOD).

MDL is a primary research facility for the Jet Propulsion Laboratory (JPL) Center for Space Microelectronics Technology (CSMT) and is operated by JPL's Space Microelectronic Device Technology Section (346). MDL enables the development of a multitude of advanced space microelectronic devices such as infrared detectors, millimeter and submillimeter wave sensors, optoelectronic devices, and electronic neural networks. Solid-state devices down to submicron feature size are fabricated in MDL using silicon, III–V compound semiconductors, amorphous semiconductors, and superconductors. These devices are characterized for their electrical, optical, and surface/interface properties.

With its state-of-the-art equipment and creative atmosphere, MDL adds a new dimension to JPL's efforts in advanced microelectronic devices for space applications.

CONTENTS

Introduction	3
Material Deposition	7
Lithography	14
Device Processing	17
Surface/Interface Characterization	24
Electrical Characterization	29
Optical Characterization	30
Acronyms	32



Floor plan of the MDL facilities. The colored areas represent clean rooms of different classes: Red ■ class 10; Yellow class 100; Blue ■ class 1,000.

INTRODUCTION

The Microdevices Laboratory (MDL) is a 38,000-square-foot facility that encompasses clean rooms for thin-film material deposition and device processing and conventional laboratories for surface/interface and bulk electrical and optical characterization. The clean rooms are divided into four categories (classes 10, 100, 1000, and 100,000) and are arranged in conventional bays (work areas) and chases for mechanical pumps and utilities.

The three-story MDL building is designed to provide a high-quality working environment for the staff. Located above the conventional laboratories are two levels of offices that accommodate approximately 65 people. This convenient location is designed to encourage a high level of synergism and useful collaboration among scientists and technologists, enabling the shared benefits of key equipment and experienced support staff.

The air handling and exhaust systems are located on the second level, which is built on a separate foundation above the clean rooms. This construction, along with a half-inch "break" around the perimeter of the clean room envelope and the molecular beam epitaxy area, allows for the vibration-isolated floors required for submicron device fabrication.

The MDL facility exceeds all the latest federal and state safety codes and regulations. All toxic and pyrophoric gases are stored in autopurge gas cabinets in a gas bunker. These gases are distributed to the point of use using N_2 gas-purged coaxial stainless steel pipes. At the point of use, the valves, regulation, etc. are enclosed in exhausted secondary enclosures to prevent any user exposure in case of leaks.

A state-of-the-art MDA sensing system monitors toxic and pyrophoric gases; combustible gases are monitored by a Sierra monitoring system. In the event of an earthquake, two seismic sensors will immediately shut off hazardous gases at their bunkered source. All monitoring systems are integrated into an MDI Alarm/Supervisory system, which is connected to a 24-hour JPL security system. Precautions at MDL are designed to provide occupants with a high degree of occupational safety.

MDL provides a wide range of support for thin-film material deposition, end-to-end device fabrication, and surface/interface and bulk electrical and optoelectronic characterization.

The thin-film material deposition techniques available include:

- DC- and rf-magnetron sputtering for semiconductors, superconductors, metals, and insulators.
- Electron beam evaporation for metals and insulators.
- Electron–cyclotron resonance for dielectrics.
- Liquid-phase epitaxy for III–V compound semiconductors.
- Metallorganic chemical vapor deposition for compound semiconductors.
- Molecular beam epitaxy for III–V compound semiconductor materials and devices.
- Silicon molecular beam epitaxy for silicon devices.
- Plasma-enhanced chemical vapor deposition for a-Si.

For thin-film material surface and interface characterization, MDL offers several state-of-the-art capabilities such as:

- Scanning electron microscopy.
- X-ray photoemission spectroscopy.
- Scanning Auger microscopy.
- Transmission electron microscopy.
- Scanning tunneling microscopy.

MDL's device processing capabilities include:

- E-beam lithography (80 Å spatial resolution).
- Optical lithography with three mask aligners.
- Dry and wet etching for superconducting and semiconductor devices.
- Metallization using dc- and rf-sputtering, or electron beam and resistive evaporation.
- Thermal processing for oxidation, diffusion, and annealing.

The bulk electrical characterization capabilities include:

- 4-point probe resistivity.
- Current–voltage.
- Capacitance–voltage.
- Hall effect.

The optoelectronic characterization capabilities include:

- Photoluminescence.
- Raman spectroscopy.
- Fourier transform infrared spectroscopy.

The various capabilities available in MDL are detailed in the six sections that follow in this brochure. Within each section, specific techniques are described, available systems and specifications are defined, and the programs currently supported by each technique are listed.

Molecular Beam Epitaxy (Si and SiGe)

SYSTEM TYPE: Riber EVA 320

WAFER SIZE/MOUNTING: 2" dia wafers/nonclamping annular retaining ring

SOURCES: Silicon and germanium using electron beam evaporation, solid arsenic (n-doping), and boron (p-doping) from HBO_2 using effusion cells

IN SITU CHARACTERIZATION: Reflection high-energy electron diffraction (RHEED)

The Silicon MBE system is dedicated to the fabrication of long wavelength infrared detectors.

Silicon molecular beam epitaxy (MBE) is a technique that allows the growth of thin single-crystal layers of a variety of Group IV materials on silicon substrates. These materials include silicon (Si) or silicon germanium (SiGe) alloy layers with abrupt, tailored doping profiles, metal silicides, and insulators. In addition to growth on bare silicon substrates, the low-growth temperatures of MBE allow growth on preprocessed wafers without disturbing existing structures or devices.

The MBE system's loadlock is connected to a dry-nitrogen glove box, where final chemical preparation of substrates is performed. The growth of epitaxial layers is carried out in ultrahigh vacuum using electron beam and effusion oven evaporation sources. Evaporant fluxes are accurately controlled by a Sentinal III electron-impact sensor deposition controller. The Si substrates are rotated and heated during deposition, and the crystalline quality of the growing layers is monitored by reflection high-energy electron diffraction (RHEED). Substrate temperature is monitored both by thermocouples in close proximity to the wafer and by infrared pyrometry.

The MBE system is also linked via glove boxes to a surface analytical system, allowing scanning Auger electron spectroscopy (AES) and X-ray photoelectron spectroscopy (XPS) to be performed on MBE-grown samples without exposing them to air.

Programs currently supported by this equipment include:

- Si/silicide Schottky internal photoemission detectors for application to medium and long wavelength infrared imaging arrays having excellent pixel-to-pixel uniformity and compatibility with well-established silicon technology.
- SiGe/Si heterojunction internal photoemission detectors having improved quantum efficiency and tailorable cutoff wavelength for application to mid-wavelength and long wavelength infrared imaging arrays.
- Advanced silicides/Si structures for enhancing the responsivity and extending the wavelength range of Schottky infrared imaging arrays.

Molecular Beam Epitaxy for Photonics and Infrared Devices

III–V MBE system for photonics and infrared devices. Operator is making an adjustment during sample loading for growth of quantum-well structures.

SYSTEM TYPE: Riber 2300

WAFER SIZE/MOUNTING: 2" dia wafers using either indium solder or indium-free mounting

SOURCES: Elemental solid Ga, Al, In, and for the growth of binary (GaAs, AlAs, InAs), ternary (AlGaAs, InGaAs, InAlAs), and quaternary (InGaAlAs) compounds as well as Si and Be for n- and p-doping, respectively

PROCESS CONTROL: A Microvax II computer controls effusion cell temperatures, shutter positions, and substrate temperatures.

ADDITIONAL FEATURE: The loading/preparation module is connected to a dry-nitrogen glove box where final chemical treatments of the wafers can be performed in an inert gas atmosphere.

Molecular beam epitaxy (MBE) is an ultrahigh vacuum evaporation technique that slowly and precisely controls growth rate using fast shutter motions to start and stop the deposition of constituent elements and dopants on the crystal surface. Abrupt changes and accurate profiles of composition and doping as well as precise control of layer thicknesses can therefore be achieved with atomic monolayer precision.

To further control the growth process, in situ reflection high-energy electron diffraction (RHEED) is used. RHEED provides information on the structure and the smoothness of the growing surface. In addition, the growth rate can be accurately monitored through oscillations in the diffraction intensity induced by the layer-by-layer growth. Growth interruptions can be used for further smoothing of the surface, which results in near-perfect heterostructure interfaces.

MBE provides the conditions for bandgap engineering, in which the properties of a semiconductor structure can be tailored to meet the requirements of a specific device application. For example, quantum well structures can be designed and fabricated. Such structures confine charged carriers to ultrathin layers, which are thin enough for quantum-size effects to have a significant influence on material properties.

Programs currently supported by the photonics MBE include:

- Spatial light modulators (SLMs) for optical computing and signal processing.
- Semiconductor laser development, and surface-emitting grating lasers for optical interconnects, and highly efficient laser diodes for optoelectronic integration.
- Optoelectronic integrated circuits (OEICs) for optical communication, signal processing, and neural networks.
- Long wavelength infrared (LWIR) detectors for the 8–17 μm range based on III–V semiconductors.

III–V Molecular Beam Epitaxy for High-Speed Devices

SYSTEM TYPE: Riber 2300

WAFER SIZE/MOUNTING: 2" dia wafers using either indium solder or indium-free mounting

SOURCES: Elemental solid Ga, Al, In, and As for major constituents, and Si and Be as dopant sources

IN SITU CHARACTERIZATION: Reflection high-energy electron diffraction (RHEED), residual gas analyzer (RGA), line-of-sight quadrupole mass spectrometry (QMS) in the growth chamber, and ultrahigh vacuum sample transfer to an X-ray photoemission spectroscopy (XPS) system

This system is based on the research and development configuration of the Riber 2300 MBE series. The growth chamber effusion cell group, manipulator, and electronic and computer control equipment for this system are identical to that of the photonics MBE system.

In addition, this system has normal incidence pyrometry and line-of-sight quadrupole mass spectrometry (QMS). The QMS system is designed with skimmer and chopper for modulated beam mass spectroscopy that follows oscillations in the sticking coefficient of As_2 and As_4 during growth for quantification of growth parameters for strained-layer epitaxy in the InGaAlAs/GaAs system. This chamber is also equipped with a 30 keV RHEED gun that has computer control of angle of incidence for comprehensive RHEED control of growth conditions.

The video signal is analyzed with a custom bit-slice microprocessor for real-time specular-beam intensity and surface-lattice constant analysis. The data are then recorded on an S-VHS VCR for subsequent frame-by-frame analysis by dedicated RHEED analytical equipment. This growth chamber is also interconnected to a 20 MW CO_2 laser and a 25 MW excimer laser for laser-assisted epitaxy. Two sets of optical ports permit 40 degree and near-grazing incidence irradiation during growth.

The growth chamber is interconnected through a vibration-isolated ultrahigh vacuum (UHV) gate valve to a UHV scanning tunneling microscope (STM) and metal deposition chamber for atomic resolution studies of surface structure and spectroscopy. The metallization capability supports UHV contact fabrication for ballistic electron emission microscopy (BEEM). The sample introduction chamber entrance component is integrated with a custom three-chamber dry box. This dry box has one chamber for direct sample introduction and a second chamber for chemical spin-etching of GaAs or Si substrates and a substrate sample holder mounting. The third chamber is a vacuum-evacuable introduction system.

Programs currently supported by this equipment include:

- High electron mobility transistor (HEMT) heterostructures for microwave and millimeter wave, low-noise and power, transistors and oscillators.
- Submillimeter-wave Schottky diode mixers for heterodyne spectroscopy.
- Barrier-intrinsic-n$^+$ (BIN) diodes for submillimeter-wave sources.

III–V MBE system is used in the growth of high-speed heterostructures and infrared devices.

Liquid-Phase Epitaxy

LPE reactors are monitored by worker during solid-state laser growth.

SYSTEM TYPE: Alzeatek (Qtn = 2)

SOURCE MATERIALS: Aluminum, gallium, indium, phosphorus, arsenic, and antimony

SUBSTRATE SIZE: 1" dia or 1.5 x 2 cm

Liquid-phase epitaxy (LPE) is a technique in which thin crystalline films are grown from a saturated or supersaturated liquid "melt" onto an oriented single-crystal substrate. The epitaxial layer or layers will assume the same crystalline lattice dimensions and orientation as the substrate. LPE technology has led to the development of high-quality heteroepitaxial semiconductor layers in III–V binary, ternary, and quaternary compounds for devices such as laser diodes, field effect transistors, and solar cells.

This technique yields slow, controllable growth rates, better compositional control, and more favorable segregation coefficients for impurities that result in high-purity layers. It also allows incorporation of desired impurities that determine the electrical properties of the layer.

LPE growth is carried out in a graphite "boat" of the common horizontal slider variety. The boat is made up of three separate pieces, each fabricated from special high-purity graphite. The top piece consists of a series of several machined bins in which melts of differing compositions are confined. The second piece (the slider) sits underneath. The third piece supports the slider and maintains good contact between the slider and the bins, which confine the melts.

Growth takes place when the slider is positioned so that the substrate is in contact with one of the melts. The thickness of the growth layer is determined by the length of time the substrate is held in contact with the melt. Sophisticated heteroepitaxial structures (that is, structures containing multiple layers of different compositions) can be prepared by positioning the slider so that the substrate is brought into contact with different composition melts in a particular sequence.

Programs currently supported by the LPE systems include:

- Development of InGaAsSb/AlGaAsSb lasers with a 2.1 μm wavelength output for injection locking of Er:Tm:Ho:YAG solid-state lasers used in lidar systems for airborne wind shear detection.
- Development of narrow-linewidth AlGaAs/GaAs lasers at 727 nm wavelength output for injection locking of Ti:sapphire solid-state lasers.
- Development of high-power 1.63 μm laser arrays for pumping Tm:Ho:YAG solid-state lasers using InGaAsP/InP layers.

Metallorganic Chemical Vapor Deposition

SYSTEM TYPE: General Air

SUBSTRATE SIZE: 1" dia wafer

SOURCES: Trimethyl gallium, trimethyl aluminum, trimethyl indium, AsH_3, PH_3, CH_2Mg (p-dopant), and H_2Se (n-dopant)

DEPOSITION MODE: Atmospheric/low pressure

The General Air MOCVD system is loaded by worker for the growth of InGaAlP lasers.

Metallorganic chemical vapor deposition (MOCVD) is used for epitaxial deposition of compound semiconductors. The MOCVD technique takes advantage of the high-vapor-pressure property that many metallorganic compounds have, which enables them to easily dissociate at moderate temperatures (normally less than 500 °C) in an irreversible manner.

A vapor mixture of the organic molecules and hydrides that contain the constituent elements of the compound layer to be grown is transported, by a carrier gas such as hydrogen, to the surface of a hot substrate in the growth chamber where the pyrolysis reaction and deposition occur. As a result of this reaction, a nonvolatile solid like GaAs is deposited onto the substrate and the by-product, methane gas, exits the reactor chamber.

A wide range of compound semiconductors can be deposited by changing the reactant gases introduced into the reactor tube. This process allows heterojunction growth between different materials or semiconductor layers of graded composition that are extremely important in advanced laser structures. MOCVD is especially useful for growing III–V semiconductor heterostructures of phosphorus-bearing compounds, since these materials are very difficult to grow by other epitaxial techniques.

The General Air MOCVD system uses a 1" dia, water-cooled horizontal quartz reactor tube with a radiatively heated graphite susceptor. Its gas-handling component consists of a stainless steel tubing network with welded/VCR connections and utilizes a vent/run gas manifold for fast switching of the process gases between the reactor and vent (bypass) line for sharp interface transition in multilayer structure growth.

Gas flow rates are controlled by electronic mass flow controllers and temperature control baths that keep the metallorganic sources at fixed temperatures for a constant vapor pressure and vapor supply rate. The entire growth process and process parameters are fully computer controlled. Any alloy of these materials can be readily grown.

An additional rapid switching capability permits the operation of this system in an atomic layer epitaxy (ALE) mode in which the growth proceeds one monolayer at a time with each reactant gas pulse.

Programs currently supported by the MOCVD include:

- InGaAlP lasers with emission wavelengths in the 530–640 nm range for optical pumping of solid-state alexandrite lasers.
- InAs–InGaSb strained-layer superlattices for infrared detectors with sensitivity to 25 μm wavelengths.

Electron Cyclotron Resonance/Plasma-Enhanced Chemical Vapor Deposition

SYSTEM TYPE: Custom fabricated using an electron cyclotron resonance plasma source manufactured by Applied Science and Technology, Inc.

SUBSTRATE SIZE: Up to 4" dia

DEPOSITION TEMPERATURE: 200–1000 °C

SOURCE GASES: Methane, silane, phosphine, diborane, hydrogen, argon, oxygen, ammonia, and nitrogen; the available ECR plasma gases are hydrogen, nitrogen, argon, methane, and silane.

IN SITU CHARACTERIZATION: Optical multichannel analyzer optical detection system with a Spex Triplemate monochromator, coherent anti-Stokes Raman spectroscopy, mass spectroscopy, and laser-induced fluorescence

OPERATING FREQUENCY: 2.45 GHz for electron cyclotron resonance and 13.56 MHz for the radio frequency system

An rf plasma-enhanced CVD system coupled with an ECR microwave plasma source is monitored by worker during the growth of diamond films.

Electron cyclotron resonance (ECR) microwave plasma and radio frequency (rf) plasma-enhanced chemical vapor deposition (PECVD) provide a means for depositing amorphous, microcrystalline, and epitaxial films. The PECVD machines in MDL are state-of-the-art, low-pressure, gas-phase, thin-film deposition systems. These deposition systems are capable of depositing electronic and optical thin-film materials, including silicon oxide, silicon nitride, silicon oxynitride, silicon carbide, germanium nitride, amorphous silicon, amorphous carbon, boron nitride, epitaxial silicon, and diamond.

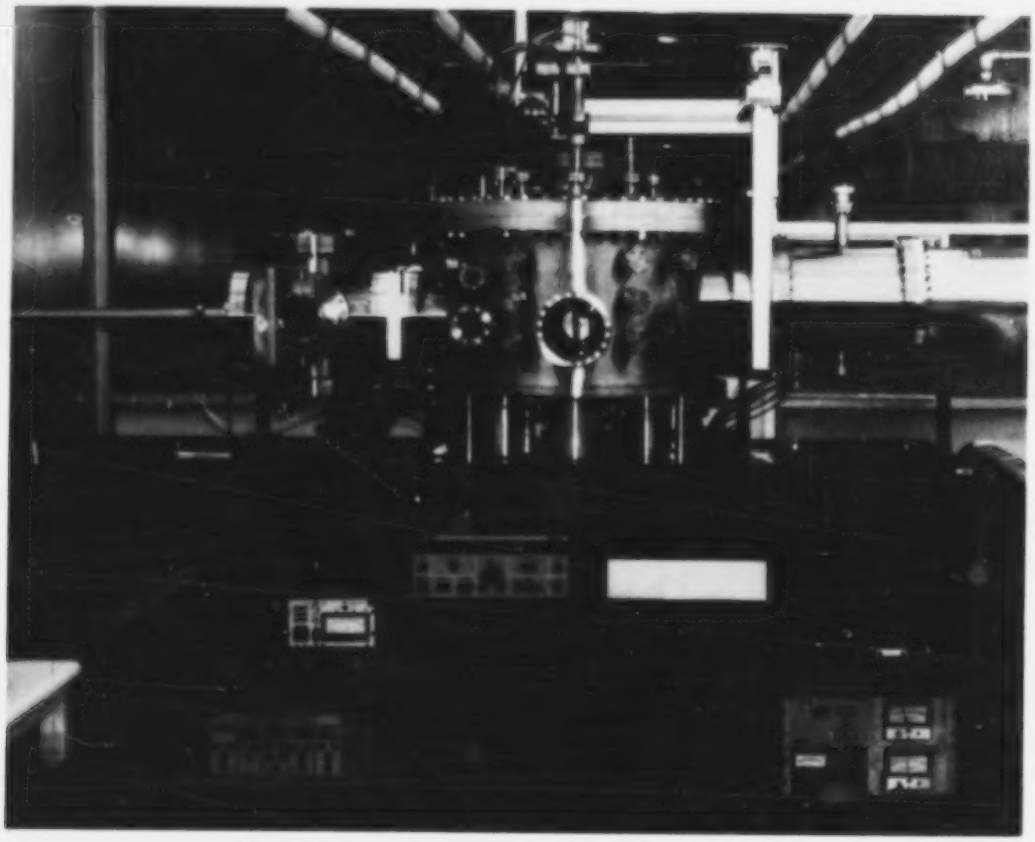
The ECR system is coupled by a high-vacuum gate valve with an rf PECVD system. The gas-handling system consists of a four-channel plasma gas input and an eight-channel source and doping-gas input to the plasma and deposition chamber, respectively. The substrates are mounted on a sample stage, which is rf-induction heated up to 1000 °C. The sample stage can travel from a distance of 15 cm below the aperture of the ECR chamber to a distance of 16 cm above the aperture. A dc- or rf-bias voltage can be applied to the rf heating sample stage. The use of relatively low-energy ions during film deposition tends to minimize damage to the growing surface while providing the high plasma density for promoting nucleation and growth.

Programs currently supported by PECVD include:

- a-Si and a-Si:C for photovoltaic and optical applications.
- Amorphous silicon thin-film programmable resistor arrays for neural network hardware.
- ECR deposition for diamond and diamond-like films for high-temperature electronics, hard optical coatings, X-ray lithography masks, and tribological applications.

Superconductor–Insulator–Superconductor Deposition

Custom sputtering system is dedicated to the deposition of superconductor–insulator–superconductor tunnel junctions.



SYSTEM TYPE: K.J. Lesker custom design sputtering system

MATERIALS: Nb, NbN, Al, and MgO

SUBSTRATE SIZE: Up to 3" dia silicon, sapphire, quartz, etc.

This system is used for deposition of superconductor–insulator–superconductor (SIS) tunnel junctions made of refractory superconductors niobium (Nb) and niobium nitride (NbN). The tunnel junction technologies supported are $Nb/AlO_X/Nb$ and NbN/MgO/NbN.

The refractory metals Nb and NbN are deposited by dc-magnetron and reactive dc-magnetron sputtering, respectively. Aluminum is rf-magnetron sputtered and oxidized in situ to form AlO_X insulator barriers.

MgO insulators are deposited directly from pressed targets by rf-magnetron sputtering. The system will handle wafers up to 3" and is loadlocked for fast sample turnaround. The sputter deposition sources use 3" planar targets.

The system also contains a thermal evaporator for low-melting-point metals (Au) and a 5 cm Kaufman ion mill for cleaning and patterning films.

The system is dedicated to the fabrication of superconducting structures for:

- SIS tunnel junctions for submillimeter-wave mixers.
- Josephson effect submillimeter-wave oscillators.
- Superconductor/semiconductor hybrid structures.

Electron Beam

SYSTEM TYPE: JEOL JBX-5DII™

RESOLUTION/FIELD SIZE: 8 nm/80 μm (high-resolution mode); 100 nm/1.6 mm (wide-field mode)

ACCELERATING VOLTAGE: 50 or 25 kV

BEAM CURRENT: 5 pA to 1 mA

CATHODE TYPE: Single crystal LaB_6

POSITIONING RESOLUTION: 5 nm (monitored by optical interferometry)

REPOSITIONING ACCURACY: 50 nm

FIELD-STITCHING ACCURACY: 50 nm

SUBSTRATE SIZE: Up to 6" x 6" (5" x 5" written area)

INPUT FILE FORMAT: Either GDSII or CIF files can be used

MODE: Direct-write/mask-making

SUPPORT FACILITIES: Resist spin-coaters, resist bake ovens

ADDITIONAL CAPABILITIES: Cassette feed — allowing it to expose up to 12 wafers in succession under automatic control

Electron beam lithography is a technique used for producing patterns in an imaging medium that can then be transferred onto thin films of various materials such as metals, dielectrics, semiconductors, and superconductors. (Fabrication of electronic and photonic devices consists of sequential patterning of layers of these materials.)

The imaging medium, called "resist," is typically a polymeric material that undergoes a physical change when exposed to an electron beam. After exposure to the electron beam, the resist-coated substrate is immersed in a chemical developer that selectively removes the patterned resist. The pattern produced in the resist can be replicated in the underlying thin film by etching the film (using either wet chemical etching or dry plasma etching). Alternatively, some materials can be patterned by a technique known as lift-off, in which resist is applied and patterned prior to the deposition of the thin film so that when the resist is stripped away, the thin film remains on the substrate only in those areas in which the resist had been absent.

One of the unique features of this lithography system is its capability to draw essentially arbitrary curved shapes based on mathematical descriptions. This feature is useful for fabricating certain types of devices, such as planar-spiral submillimeter-wave antennas.

The JBX-5DII™ is being used in a number of projects, including:

- Superconductor–insulator–superconductor submillimeter wave detectors.
- Distributed-feedback laser diodes and surface-emitting grating lasers.
- Neural network synaptic arrays.
- High-speed devices for low-noise microwave amplifiers, phased-array radar, and submillimeter-wave sources.
- Binary optical elements.

The sample introductory chamber of the JEOL JBX-5DII™ electron beam lithography system is loaded by operator prior to resist patterning.

Optical Lithography

MASK-ALIGNER TYPE: Two Karl Suss MJB3-UV300 (mid-UV contact printing)

MINIMUM FEATURE SIZE: 0.4 μm

ALIGNMENT TOLERANCE: ≤ 0.25 μm

WAFER SIZE: Up to 3" (75 mm) dia up to 4.5 mm thickness

EXPOSURE UNIFORMITY: ± 3% for 2" dia; ± 5% for 3" dia

ADDITIONAL CAPABILITY: One aligner features infrared transmission backside alignment capability

SUPPORT FACILITIES: Complete support facilities, including resist spin-coaters, resist-bake ovens, and hot plates

Karl Suss MJB3 contact mask aligners in the class 10 area of MDL are utilized to optically pattern photoresist at 320 nm.

Optical lithography is a technique for producing patterns in an imaging medium that can then be transferred onto thin films of various materials such as metals, dielectrics, semiconductors, and superconductors. (Fabrication of electronic and photonic devices consists of sequential patterning of layers of these materials.) The imaging medium, called photoresist, is typically a polymeric material that undergoes a physical change when exposed to ultraviolet (UV) light.

In contact-printing lithography, a glass plate bearing the pattern to be imprinted on the substrate (rendered as UV-opaque and UV-transparent areas) is placed in intimate physical contact with the photoresist-coated substrate and then exposed to blanket UV illumination. After exposure to UV light, the photoresist-coated substrate is immersed in a chemical developer, which selectively removes the patterned resist. The pattern produced in the resist can be replicated in the underlying thin film by etching the film (using either wet chemical etching or dry plasma etching).

Alternatively, some materials can be patterned by a technique known as lift-off, in which resist is applied and patterned prior to the deposition of the thin film so that when the resist is stripped away, the thin film remains on the substrate only in those areas in which the resist had been absent.

Optical lithography is used in nearly all device fabrication. Programs currently supported by lithography include:

- Superconductor–insulator–superconductor submillimeter wave detectors.
- Photonic devices such as laser diodes and spatial light modulators.
- Neural network hardware such as neural network synaptic arrays.
- High-speed III–V semiconductor devices.
- Quantum-dominated nanodevices and micromachined sensors.
- Infrared detectors.

Wet Etching

A typical paired set of MDL's wet processing benches. The white polypropylene bench is used for acid processing; the stainless steel station is used for solvent processing.

SYSTEM TYPE: Integrated Air Systems, Inc.

FUNCTIONS: Cleaning and etching of substrates and deposited layers of semiconductors, metals, or dielectrics

Wet processing is used as a semiconductor process step and is involved in virtually all fabrication work at MDL. MDL uses two types of wet benches: polypropylene benches for acid processing and stainless steel benches for solvent processing. Three of the paired sets of polypropylene and stainless steel benches within MDL are dedicated to silicon micromachining, III–V semiconductors, and general purpose processing, respectively. Additional benches are available for silicon and superconductor processing.

Processing capabilities include automatic, programmable hot-bath and dump-rinse cleaning, and rinser-dryer and ultrasonic treatments. These capabilities are applied to process semiconductor materials and devices (for example, silicon, gallium arsenide, metals, and dielectrics).

Dry Etching

The reactive ion etcher is used to anisotropically etch and delineate superconductor tunnel junction device structures.

REACTIVE ION ETCHING (RIE) SYSTEM TYPES:

Two Plasma technology systems —

- One single chamber for superconductors, utilizes chlorine- and fluorine-based chemistries
- Dual chamber: for silicon, utilizes fluorine chemistry; for III–V compound semiconductors, utilizes chlorine chemistry

SUBSTRATE SIZE: Up to 4" dia wafers

ETCHANT/DILUTANT GASES: CF_4, BCl_3, CCl_2F_2, SF_6, N_2, O_2, and Ar

ION MILLING SYSTEM TYPE: Commonwealth

SUBSTRATE SIZE: Up to 3" dia wafers

ACCELERATING VOLTAGE: Up to 1000 V

ETCHANT GAS: Argon

Reactive ion etching (RIE) is a technique for patterning thin films of metals, dielectrics, semiconductors, and superconductors; this technique is particularly well suited to very small geometry structures. Because wet chemical etching and conventional plasma etching remove material by chemical action, they exhibit excellent etch-rate selectivity among various layers of a structure — if a suitable chemical process is identified that attacks one particular layer without attacking an underlying layer of a different composition.

Wet chemical etching and conventional plasma etching processes are essentially isotropic, allowing the etchant to undercut the etch mask laterally at roughly the same rate at which it etches vertically. In state-of-the-art device structures, lateral pattern dimensions are reduced to the micron and submicron dimension so the vertical and lateral dimensions of patterned thin films are comparable. Such films cannot be etched using an isotropic etching technique.

Ion milling is a technique that uses highly directional energetic particle bombardment to remove material. Although this technique yields highly anisotropic etching, it exhibits very little etch-rate selectivity between layers of different composition since its action is essentially mechanical (at the atomic scale) rather than chemical.

This lack of selectivity can be a problem when fabricating a device that, for example, requires exposing a thin layer of material of one composition buried under a thicker layer of a different composition.

RIE combines the advantages of chemical etching and ion milling techniques, using both chemical action and bombardment in the etching process. In RIE, a reactive plasma forms semivolatile compounds on the surface of the layer to be etched. These reaction products will not leave the surface without additional energy from the highly directional bombardment.

This technique yields anisotropic etching, which resembles ion milling. In contrast to ion milling, however, the bombardment alone is insufficient to remove material without the chemical formation of a semivolatile reaction product on the surface. By choosing the appropriate plasma constituents and etching conditions, it is possible to obtain etch-rate selectivity among layers of different compositions.

The RIE capability supports the fabrication of:

- Superconducting tunnel junction device work in Nb, NbN, and YBaCuO.
- Silicon micromachined devices including accelerometers and thermal-infrared detectors.
- III–V semiconductor lasers.
- III–V semiconductor electronic devices.

The ion milling technique supports the fabrication of silicon-compatible infrared detectors.

A Commonwealth ion milling system provides highly directional energetic particle bombardment to remove material during the fabrication of silicon micromachined devices.

Thin-Film Deposition Capability

DEPOSITION FOR THIN-METAL FILMS

ELECTRON BEAM EVAPORATION SYSTEM TYPES:

Temescal BJD-1800 (cryopumped system) for refractory materials

Veeco VE-747 (diffusion-pumped system) for general purpose use

Sloan SL1800 (cryopumped system) for deposition of Schottky contacts to III–V materials

RESISTANCE EVAPORATION SYSTEM TYPES:

CHA custom design (cryopumped system) for aluminum deposition

CHA SE-600-P (diffusion-pumped system) for ohmic contacts to p-GaAs

Veeco 300 (custom modified, cryopumped system) for ohmic contacts to n-GaAs

Veeco VE-400 (diffusion-pumped system) for In, In:Zn, and In:Sn alloys

SPUTTERING SYSTEM TYPES:

Sputtered Films (turbopumped system) for general use

JPL ultrahigh vacuum custom (cryo/turbopumped system) for specific novel material fabrications

Emscope SC-500 (mechanical-pumped system) for Au deposition on SEM samples

Hummer XP (mechanical-pumped system) for Au deposition on SEM samples

SUBSTRATE SIZE: 2" and 3" dia typical — some systems accept up to 4" dia substrates

IN SITU MONITORING: Quartz crystal deposition thickness monitors on all systems, residual gas analyzers on sputtering systems

DEPOSITION FOR THIN DIELECTRIC FILMS

ELECTRON BEAM EVAPORATION SYSTEM TYPE: Sloan SL1800 (cryopumped system)

ECR SYSTEM TYPE: Microscience, Inc., custom fabricated system

SUBSTRATE SIZE: Up to 4" dia wafer

DEPOSITION TEMPERATURE: 50–300 °C

ECR SOURCE GASES: Silane, germanium tetrachloride, ammonia, oxygen, nitrogen, argon, and hydrogen

ECR SUBSTRATE BIAS: dc or rf

The Temescal BJD-1800 electron beam evaporator is used to deposit high-melting-point, refractory thin-metal films.

Essentially all electronic and optoelectronic devices require patterned thin films of metals for contacts, and some also require thin films of dielectrics for isolation, passivation, or masking. The systems listed on page 20 provide the means for depositing these metal contacts and insulating layers in semiconductor and superconductor devices, as well as for optical coatings and cermet layers for various applications.

A wide variety of metals and metal alloys may be deposited, including Al, Ag, Au, Au:Ge, Au:Pd, Au:Zn, Co, Cr, Cu, Fe, Ge, Ge:Cu, In, In:Sn, In:Zn, Ir, Mn, Mo, Nb, Ni, Pd, Pt, Si, Si:Cr, Ta,V, and W. In addition, a number of dielectrics may be deposited, including Al_2O_3, MgO, SiO, SiO_2, Si_3N_4, and TiO_2. All of the evaporators can hold several sources simultaneously, so that any compatible combination of the metals listed may be deposited sequentially in a layered structure without exposing the individual layers to air.

The electron cyclotron resonance (ECR) system is used primarily for low-temperature dielectric deposition. The high-density plasmas generated by the ECR source are ideal for reducing the substrate temperature required for deposition of such materials as silicon dioxide, which can be deposited at temperatures below 100 °C by ECR.

This system is turbopumped in order to provide a clean vacuum environment for the deposition. To further reduce contamination, this system is attached to a nitrogen-purged glove box where wafer preparation can be carried out so that the wafer can be loaded into the system without exposing it to air after the final treatment.

In the ECR system, five gas channels are plumbed to the system's plasma source, and three gas channels are connected to the process chamber. The stage is positioned vertically by a stepper motor. Essentially all system functions are computer controlled; the computer controls the deposition based on previously stored routines and logs actual parameters during a run. The computer control both reduces operator error and increases repeatability of the processes.

The ECR system is used for low-temperature deposition for passivation or high-quality dielectric layers.

These thin-film deposition systems support virtually all device processing in MDL, including several specific tasks:

- Resistor arrays for electronic neural network hardware — novel materials are prepared by reactive sputtering to obtain thin-film programmable resistor elements (using Ge:Cu and Si:Cr) for use in synaptic array structures.
- Ge:Ag and Ge:Al cermet layers for tailored emissivity optical coatings.
- Cermet layers for fabrication of resistive gate electrodes for devices such as GaAs CCDs and contiguous domain oscillators.

Semiconductor Thermal Processing

CAPABILITIES:

Silicon oxidation (wet and dry)

Silicon diffusions (p and n type)

Polysilicon deposition by low-pressure chemical vapor deposition

Annealing furnace for contact sintering

Germanium oxidation/nitridation

Germanium nitride deposition by low-pressure chemical vapor deposition

Rapid thermal contact alloying for ohmic contacts to III–V semiconductor devices

Closed-ampoule zinc diffusions into GaAs

SUBSTRATE SIZE: 2" dia for all processes except silicon oxidation, which can be performed on wafers up to 3" dia, and closed-ampoule diffusions, which are performed on small sections (~ 1 cm^2)

Thermal processing is used in the fabrication of almost all semiconductor devices. In traditional silicon processing, most of the device structure is created by oxidation and dopant introduction, either by diffusion or by implantation and annealing — all of which involve thermal processes. In III–V semiconductor devices, nonrectifying contacts must be heat-treated after deposition in order to be rendered ohmic. Passivation and dopant introduction into germanium devices are also accomplished by thermal processes.

The thermal processing facilities currently support the following areas:

- Silicon-compatible detectors for mid-wavelength infrared and long-wavelength infrared focal plane arrays using silicide Schottky barrier internal photoemission detectors and silicon/silicon:germanium heterojunction internal photoemission detectors.
- III–V devices, including lasers, infrared detectors, and high-speed electronic devices such as high electron mobility transistors.
- Germanium blocked impurity band (BIB) far-infrared detectors.

Germanium oxidation/nitridation furnace is loaded by worker during processing of germanium blocked impurity band (BIB) far-infrared detectors.

Scanning Electron Microscopes

The state-of-the-art JEOL 840F SEM with cold-cathode field emission source and 1.8 nm resolution is used to image and characterize epitaxial materials.

SYSTEM TYPES:

JEOL 840F for material characterization

JEOL IC848 for process characterization and development

Cambridge Stereoscan 100 for routine sample analysis

ELECTRON SOURCES:

JEOL 840F: cold-cathode field emission gun

JEOL IC848: LaB_6

Cambridge Stereoscan 100: prealigned tungsten hairpin filament

ACCELERATING VOLTAGES/CURRENTS:

JEOL 840F: 0.5 to 40 kV/10^{-10} to 10^{-12} A

JEOL IC848: 0.2 to 40 kV/10^{-5} to 10^{-12} A

Cambridge Stereoscan 100: 2 to 25 kV/10^{-5} to 10^{-12} A

RESOLUTION/MAGNIFICATION:

JEOL 840F: 1.8 nm/10x to 500,000x

JEOL IC848: 4.5 nm/10x to 300,000x

Cambridge Stereoscan 100: 7 nm/25x to 200,000x

IMAGING MODES:

JEOL 840F: secondary electron, backscattered electron, electron channeling pattern, and cathodoluminescence

JEOL IC848: secondary electron, backscattered electron, and electron channeling pattern

Cambridge Stereoscan 100: secondary electron, backscattered electron, and transmitted electron

SPECIMEN SIZE:

JEOL 840F: 1.25" dia through loadlock; 4" dia into chamber

JEOL IC848: 8" dia through loadlock; 9" dia into chamber

Cambridge Stereoscan 100: up to 7" dia samples

FEATURES:

JEOL 840F: custom cathodoluminescence detection system

JEOL IC848: Quantel Crystal image unit

Cambridge Stereoscan 100: Linear measurement cursor, beam-blanking unit and specimen current monitor with maximum square-wave repetition rate of 1 MHz

Scanning electron microscopes (SEMs) are used to examine the structural and compositional morphology of solid surfaces and interfaces by generating high-magnification images of the specimen. The images are displayed on a cathode ray tube (CRT) monitor by synchronizing the CRT electron beam rastering with that of a sharply focused electron beam used to probe the specimen in the microscope. The intensity variation observed on the CRT display is proportional to the detected signal, which can be secondary electrons, backscattered electrons, Auger electrons, X-rays, or cathodoluminescence.

Secondary electrons result from the inelastic scattering of the incident electron beam during penetration into the solid, and these electrons are primarily emitted within 5 nm of the surface. The resulting high-surface sensitivity can be used to image fine structural details within the resolution of the microscope.

Backscattered electrons have energies close to that of the probe beam; these electrons emanate from within a micron of the surface. The intensity of the backscattered signal is directly related to the atomic number of the material and is therefore a useful probe in the near-surface region for the specimen's chemical composition. This type of probe is ideal for examining the homogeneity of layer thicknesses in thin-film devices such as heterojunction junction lasers, high electron mobility transistors, and quantum-well-based infrared detectors.

The interaction of the high-energy electron probe with the solid results in the generation of electron-hole pairs within approximately 1 μm of the surface. In semiconductors, depending on the crystal quality, dopant types, and sample temperature, these pairs recombine across the bandgap by a variety of radiative and nonradiative processes. By studying the cathodoluminescence emitted from such processes on a microscopic scale, it is possible to measure critical electronic and material properties (for example, minority carrier lifetimes, diffusion lengths, carrier concentrations, band levels, defect densities, and sample inhomogeneities that can occur during growth and fabrication). These electronic and material properties influence the performance of electronic and photonic devices. Presently, a custom-made cathodoluminescence detection system, which has been designed and implemented at JPL, is operational on the JEOL 840F SEM, a state-of-the-art electron microscope with ultrahigh resolution capability.

The JEOL IC848 SEM is a similar unit with only slightly reduced resolution and has the capability of handling large substrates. Located in the class 100 processing area, it provides needed support to the E-beam lithography tasks and in-process device fabrications. With minimal instruction, researchers can be given adequate preparation to conduct their own studies on the JEOL IC848 SEM. It has a sample loadlock, and a wide range of accelerating voltages, magnification factors, working distances, sample positions, and probe currents. For the most difficult problems, the Crystal image unit by Quantel is used for an acquisition and process subsystem. The Crystal enables image averaging, image differencing, contrast/brightness stretching, data storage/retrieval, and automatic critical dimension measurement. It has the ability, through hardware, to apply one of 12 built-in or user-designed (up to 5 x 5 pixel) two-dimensional image filters. It also has an interface with an IBM PC and a PC-based software package for further image analysis.

The Stereoscan 100 SEM is designed for high performance, versatility, and ease of use. Since minimum operator training is required to produce high-quality micrographs, students or inexperienced operators can train on the Stereoscan 100 before they begin work on the more complex and sensitive units available at MDL.

The JEOL 840F SEM is currently being used to characterize epitaxial material for lasers, infrared detectors, and high electron mobility transistors.

The JEOL IC848 is being used for:

- Evaluation of the resolution capabilities of the electron beam lithography system.
- Inspection of SIS submicron tunnel junctions during fabrication for establishing an RIE process with correct etch profile.
- Inspection of submicron wire electrode structures for controlling lateral ballistic tunneling electron devices. Metal lift-off procedures were developed for direct-write electron beam lithography masks.
- Evaluation of photolithography resist profiles while establishing proper exposures and development techniques.

X-Ray Photoelectron Spectroscopy/ Scanning Auger Microprobe

SYSTEM TYPE: Surface Science Instruments SSX-501 X-ray photoelectron spectrometer

SCANNING AUGER MICROPROBE (SAM) CAPABILITY: Kratos electron gun and secondary electron detector

LATERAL RESOLUTION: 1 μm for SAM

WAFER SIZE: Up to 7" dia

PROFILING: Depth profiling by in situ argon ion etching

CONTROL/DATA ANALYSIS: Hewlett-Packard 320 series computer and a Kevex 8000 graphics workstation

The Surface Science Instruments SSX-501 XPS system is used to analyze surfaces through nondestructive chemical characterization techniques.

For many device and materials applications, nondestructive chemical surface characterization is a desirable process. For this purpose, the techniques of choice are X-ray photoelectron spectroscopy (XPS), sometimes also called ESCA (electron spectroscopy for chemical analysis), and Auger electron spectroscopy. When the latter is combined with a scanning capability, it is often known as a scanning Auger microprobe (SAM).

Both XPS and SAM have the same high surface sensitivity, sampling the top 20–50 Å of a sample, since both techniques obtain information by detecting electrons in the same energy range. The Auger electrons are excited by a focused electron beam, whereas the XPS photoelectrons are excited by monochromatic X-rays. SAM has the advantage of high spatial resolution (~ 0.3 mm, compared to 150–1000 mm for XPS). However, XPS has the advantage of high-energy resolution (~ 0.5 eV, compared to several electronvolts for SAM), which makes it possible to identify oxidation states and other chemical information.

SAM is used for detecting samples with minute features (for instance, electronic devices). XPS is most useful in identifying chemical states and measuring insulators; it is also used for samples that would be degraded by the SAM electron beam (organics or inorganics in a high oxidation state).

XPS/SAM capabilities have been used to support nearly all device fabrication programs in MDL. These techniques may be used not only during device development, but also for completed devices to identify component failure modes. In addition, surface chemical reactions and constituent out-diffusions that occur over long periods of storage or use may be observed in device structures utilizing XPS and SAM.

Transmission Electron Microscopy

SYSTEM TYPE: Akashi Beam Technology ABT-002B

RESOLUTION: 1.7 Å point to point

SAMPLE MANIPULATORS: Standard transmission electron microscope mounts and two double-tilt sample holders with low-temperature (to 77 °K) and high-temperature (to 800 °C) capability

DATA SYSTEM: Reflection electron microscopy manipulator Gatan video imaging system — standard photographic plate exposure capability

IN SITU ANALYTICAL: Princeton Gamma Tech Energy dispersive X-ray analyzer and fiberoptically coupled cathodoluminescence analyzer

SAMPLE PREPARATION: Gatan Disc Grinder; Gatan Dimpler; Gatan Duo Ion Mill with chemically assisted ion beam etch capability and standard polishing hardware

The Akashi Beam Technology ABT-002B transmission electron microscope provides 1.7 Å point-to-point resolution.

Transmission electron microscopy (TEM) is an analytical tool that allows imaging on the angstrom scale. Imaging is accomplished by sending a high-energy electron beam through a thinned specimen (typically 300–2000 Å) to form either a real-space image or a diffraction pattern. TEM is useful for identifying crystalline phases, examining crystallographic defects such as dislocations, and evaluating device structure parameters such as interface flatness and abruptness.

The ABT-002B TEM operates at 200 keV, with a point-to-point resolution of 1.7 Å. This high resolution allows lattice imaging of single columns of atoms in Si-based, compound-semiconductor, and high-temperature-superconductor heteroepitaxial structures. A subnanometer probe, combined with digital recording of both real-space and diffraction information, gives microstructural information on the scale of the quantum devices being grown. X-ray and cathodoluminescence spectrometers provide further chemical and defect mapping capabilities.

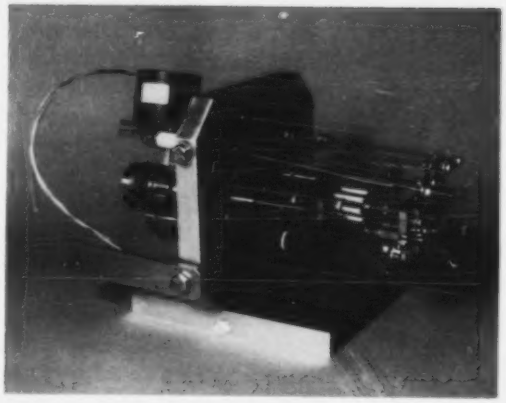
The ability of the machine to record high-resolution microdiffraction patterns allows both strain and chemical composition to be determined. Matching recorded patterns with computer simulations produces very accurate lattice parameter determinations. The behavior of beam-induced-charged species is studied specifically for cathodoluminescence processes in quantum confinement structures. The wide temperature range attained at the sample enables in situ annealing studies on highly strained lattices.

The specific problems currently being addressed with the TEM in MDL include:

- Morphology and strain in three-dimensional silicides.
- Epitaxially grown InAs/GaAs superlattices.
- Strain in the SiGe system and changes in its molecular beam epitaxy growth mode.
- Thin films of high-temperature superconductors.

Scanning Tunneling Microscopy/ Ballistic Electron Emission Microscopy

Ultrahigh vacuum scanning tunneling microscope (STM) allows imaging of surfaces with atomic resolution.



STM TYPES: One ultrahigh vacuum; one 77 °K; one 4 °K

SPATIAL RESOLUTION: 0.5 nm lateral, 0.01 nm vertical

I–V ENERGY RESOLUTION: 5 MeV

SAMPLE SIZE: Up to 1 x 1 cm

Scanning tunneling microscopy is a near-field electron microscopy technique capable of imaging surfaces with atomic resolution. The scanning tunneling microscope (STM) is one of a class of such probes, most of which are based on quantum mechanical tunneling of electrons between a conducting surface and a sharp tip positioned a few atomic diameters away. Unlike conventional scanning electron microscopes, STMs yield true three-dimensional topographs; the apparatus can be operated in liquid and gaseous environments in addition to vacuum. The low-energy electron beam causes negligible sample damage as compared to SEMs.

A major advance in the study of interfaces has been made by the invention of ballistic electron emission microscopy (BEEM) at MDL. BEEM uses an STM apparatus as a source of ballistic electrons or holes in a semiconductor/metal structure. The transmission of these carriers through a multilayer structure is measured as a function of beam energy and position. By transmitting carriers through an interface into a semiconductor, extrema in the conduction or valence band structure can be determined with energy resolution of a few megaelectronvolts and spatial resolution of approximately 10 Å. BEEM has been used to study interfacial layers and Fermi-level pinning in metal/semiconductor structures, band lineups and transmissions across abrupt semiconductor heterojunctions, and transport and scattering in thin-metal films.

STM/BEEM uses include:

- Optimizing lateral uniformity of epitaxial silicide interfaces.
- Measuring band offsets in III–V heterostructures.
- Characterizing interdiffusion at metal/III–V interfaces.
- Imaging superconducting energy gaps.
- Evaluating surface preparation techniques for molecular beam epitaxy.

The I–V/C–V electrical characterization system in MDL is used for dopant profiling and interface characterization of device structures.

MDL electrical characterization capabilities include basic electrical measurements on thin-film materials, at wafer level, or on packaged devices. Wafer probing is possible using either a conventional probe station housed in a shielding enclosure or a cooled-stage probe station. Fixturing is available for testing packaged devices.

A range of fundamental electrical measurements can be performed, including current–voltage measurements for testing dc electrical performance of diodes, detectors, and transistors; capacitance–voltage and conductance–voltage measurements for dopant profiling and interface characterization; and Hall effect measurements for determining the quality of epitaxial layers.

TECHNIQUES:

Four-point-probe resistivity

Current–voltage (I–V) down to 4.2 °K

Capacitance–voltage (C–V) down to 4.2 °K

Conductance–voltage (G–V) down to 4.2 °K

Hall effect down to 9 °K

A dc parameter measurement of multiterminal devices

EQUIPMENT:

Room temperature shielded probe station (Micromanipulator)

MMR K-20 cooled probe station

HP 4145B semiconductor parameter analyzer

HP 4275 10 kHz–10 MHz multifrequency LCR meter

HP 4192A 5 Hz–13 MHz impedance analyzer

Boonton capacitance meter

MONOCHROMATORS:

Two SPEX model 1702/04, 0.85 m, 0.2–6.0 μm with interchangeable gratings

Jobin-Yvon model HR 640, 0.64 m, 0.2–10.0 μm with interchangeable gratings

Two PTI model 01-001, 0.25 m, 0.2–17.6 μm with interchangeable gratings

Jobin–Yvon model DR 320, 0.32 m subtractive monochromator

LIGHT SOURCES:

5 W Ar-laser, Continental model 3000

10 W Ar-laser, Spectra Physics model 2020

Dye laser, continuously tunable over 0.55–1.0 μm with interchangeable dyes, Spectra Physics model 375B

12 mW HeNe laser, Newport

5 mW HeNe laser, NEC

0.5 mW HeNe laser, Melles Griot

0.5 mW five-line tunable HeNe laser, PMS Electro-Optics

Black-body source, ORIEL model 66300

75 W Tungsten-Halogen lamp

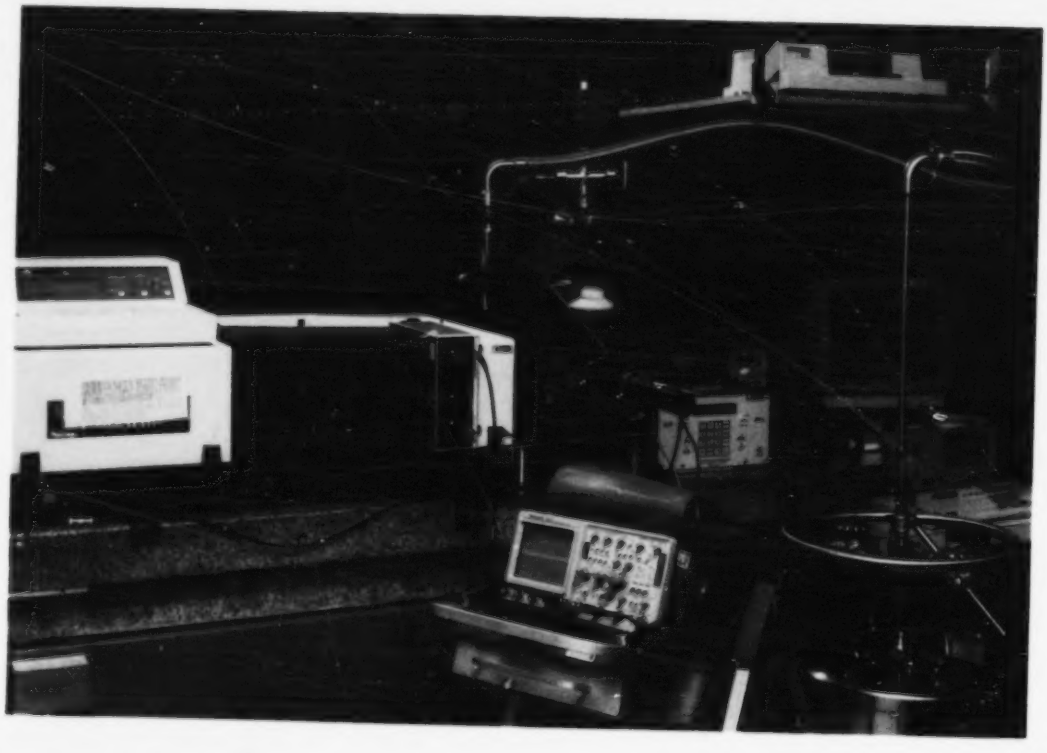
DETECTORS:

LN_2 cooled InSb detector, 1–6 μm, Hamamatsu

Si detector and preamplifier, 0.4–1.1 μm, Hamamatsu

LN_2 cooled InAs detector, 1–3.1 μm

LN_2 cooled InGaAs detector, 1–3 μm, Electro-Optical Systems



The Fourier transform infrared (FTIR) spectrometer allows on-site spectral analysis of coatings and lasers in the infrared wavelengths.

LN_2 cooled Ge detector, 0.5–1.6 μm, North Coast

High-pixel density, low-noise Si CCD, Photometrix

Thermoelectrically cooled GaAs:Cs photomultiplier, 0.4–0.9 μm

Thermoelectrically cooled Ge detector, 0.5–1.6 μm

Calibrated large area Si detectors, 0.3–1.1 μm, United Detector Technology

CHOPPERS:

Three mechanical choppers, 3–4000 Hz, Stanford Research Systems, model SR 540

Acousto-optic modulator, over 100 kHz, NEC model OD-8813A

FOURIER TRANSFORM INFRARED (FTIR) SPECTROMETER:

Covering 0.8–22 μm with interchangeable beam splitters; has a pyroelectric DTGS detector (in addition to the detectors above) covering 1–22 μm.

VIDEO SYSTEMS:

Videcon videocamera, RCA model 2000

CCD videocamera, JAVELIN, model JE2071IRGNA

CCD videocamera, COHU, model 4815-5000/0000

CCD color camera, Panasonic, model WV/CD110

Videoanalyzer, Colorado Video, Inc., model 321

Two black-and-white monitors, SONY

Color monitor, Panasonic

ELLIPSOMETERS:

Rudolf Auto-El automated ellipsometer

Manual Rudolf ellipsometers (Qtn = 2)

MDL is equipped for a wide range of optical characterization measurements for basic materials studies as well as for optoelectronic device characterization. This equipment is being used for the following types of characterization on various lasers, LEDs, and detectors:

- Temperature-dependent photoluminescence, photoluminescence excitation, photoreflectance, and Raman spectroscopy to study the electronic structure of bulk and quantum-confined semiconductor structures.
- Spectral transmission, absorption, and reflectance measurements on bulk and quantum-confined semiconductor structures as well as on devices such as spatial light modulators.
- Temperature-dependent characterization of optical detectors, including spectral responsivity and quantum efficiency.
- Characterization of semiconductor lasers, including output power, spectrally resolved near and far fields, and longitudinal mode spectra.

ACRONYMS

BEEM	ballistic electron emission microscopy
BIB	blocked impurity band
CCD	charge-coupled device
CL	cathodoluminescence
CVD	chemical vapor deposition
ECR	electron cyclotron resonance
ESCA	electron spectroscopy for chemical analysis
FTIR	Fourier transform infrared (spectroscopy)
HEMT	high electron mobility transistor
LED	light-emitting diode
LPE	liquid-phase epitaxy
LWIR	long wavelength infrared
MBE	molecular beam epitaxy
MDL	Microdevices Laboratory
MOCVD	metallorganic chemical vapor deposition
OEIC	optoelectronic integrated circuit
PECVD	plasma-enhanced chemical vapor deposition
QMS	quadrupole mass spectrometry
RGA	residual gas analyzers
RHEED	reflection high-energy electron diffraction
RIE	reactive ion etching
SAM	scanning Auger microprobe
SEM	scanning electron microscope
SIS	superconductor–insulator–superconductor
SLM	spatial light modulator
STM	scanning tunneling microscope
TEM	transmission electron microscopy
UHV	ultrahigh vacuum
UV	ultraviolet
XPS	X-ray photoelectron spectroscopy

The JPL Microdevices Laboratory is a state-of-the-art microelectronics facility dedicated to the research and development of advanced electronic materials and solid-state devices for NASA and DOD space needs. MDL's capabilities include end-to-end device fabrication down to submicron feature size, based on silicon, III–V compound semiconductors, and superconductors. Characterization capabilities include surface/interface, bulk electrical, and optical characterization.

For additional information, please contact Satish Khanna, (818) 354-4489 or Jim Rosenberg, (818) 354-2052.

NASA

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL 400-442 11/90